The following statement is a full description of this invention, including the best method of performing it known
to us:

X402-118-5D-20P.C.

This invention relates to a method of constructing a hollow, spherical curved shell-type body capable of resisting external pressures and to the body so made.

Hollow bodies capable of withstanding extremely high external pressures are in great demand for oceanographic and various other types of underwater research and exploration, and to serve as the load-carrying envelopes for underwater structures, as vehicles for men and/or instruments, or as buoyant elements for attachment to underwater vessels.

It is known to make such vessels of a solid, integral metal shell and such shells have well-known superior strength characteristics and resistance to buckling under the tremendous compressive stresses to which they are subjected at great depths below the surface of the water. Metallic vessels, however, are disadvantageous in that their strength-to-weight radio is relatively low, while their weight-to-displacement ratio is relatively high.

According to the present invention, there is provided a method of constructing a hollow, spherical body comprising the steps of preparing a number of sheets of thermosetting resin, reinforced with filaments having a desired or selected modulus of elasticity, the filaments extending from one major planar surface of the sheet to an opposite major planar surface of the sheet substantially normal to the surfaces thereof, the method comprising cutting elements from one or more sheets and assembling the elements into the form of a spherical body with the filaments aligned substantially radially of the body, characterized in that a number of elements are adhered to a backing sheet with the filaments normal to the plane of the backing sheet, the desired number of back-

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ing sheets with elements thereon are applied to a mandrel
having a spherical or part-spherical surface to form a spher-
ical structure thereon, the backing sheet being on the side
adjacent to the mandrel, any spaces between adjacent elements
are filled with uncured resin, and the structure is then sub-
jected to a curing treatment for any uncured resin.

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displacement. It is c ble of withstanding external pressure, and can be made to withstand pressures of up to thousands of pounds per square inch, the limiting pressure being determined to a large degree by the modulus of elasticity of the materials used. Such a body is thus well suited for underwater use.

The body has the further advantage over the previously known metallic vessels that it does not require special polar caps or fittings to permit access to the interior, and can be locally opened and closed as well as repaired by the removal and replacement of relatively small wall sections without impairing vessel strength.

Preferred methods according to the invention will now be described in detail, by way of example, with reference to the accompanying drawings in which:-

Fig.1 is a perspective illustration of a preferred radial-filament sphere constructed of two idential hemispheres;

Fig.2.is a fragmentary vertical section through the sphere shown in Fig.1;

Fig.3 is a perspective elevational view of the basic structural member employed in large numbers in the manufacture of the sphere shown in Figs.1 and 2;

Fig.4 is a similar view of the said member as modified prior to use in the actual build-up of the hemispheres;

Fig.5 is a plan view of the member shown in Fig.4 and illustrates a further structural modification thereof which is effected prior to the hemisphere-building operation;

Fig.6 is an elevational view of a partly built-up hemisphere which when completed is to be used in making the sphere of Fig.1;

Fig.6a is a fragmentary diagrammatic illustration of the manner of building of the hemisphere shown in Fig.6 from the structural members of Fig.5;

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Fig. 7 is a diagrammatic illustration of the effect of compressive stresses on a unidirectional or parallel-filament member of the type employed in the body according to the present invention;

Fig. 8 is a perspective illustration of another preferred sphere constructed of two identical hemispheres;

Fig. 9 is a plan view of a built-up intermediate structural member employed in building up the hemispheres used in constructing the sphere shown in Fig. 8;

Fig. 9a is a somewhat enlarged perspective illustration of the starting structural member employed in building up the intermediate member shown in Fig. 9;

Fig. 10 is a side elevational view of the said intermediate member, taken along the line 10-10 in Fig. 9;

Figs. 11 and 12 are schematic elevational views of a hemispherical mandrel and illustrate the first two steps in a further preferred method of building a radial-filament hemisphere;

Fig. 13 is a sectional view taken along the line 13-13 in Fig. 12;

Fig. 14 is an elevational view of the mandrel, similar to Fig. 12, and illustrates the next step of the said method;

Fig. 15 is an elevational view of the mandrel, seen at an angle of 45° to the plane of Fig. 14, and illustrates further steps of this method.

Fig. 16 is a fragmentary diagrammatic illustration of a radial-filament sphere shell and illustrates one of the advantages of bodies produced in accordance with the present invention; and

Fig. 16a is a similar view of a conventional filament-wound sphere shell and illustrates one of the disadvantages of such a construction.

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It has been found that when a three-dimensional structure composed of a cured thermosetting resin matrix having embedded therein a multiplicity of parallel unidirectional filaments is subjected to bi-directional compressive stresses normal to the filament orientation, the filaments are stressed in tension. This is diagrammatically illustrated in Fig. 7 wherein B denotes a rectangularly prismatic structure, composed of a cured resin matrix having embedded therein a great number of filaments (not shown) all oriented parallel to each other in the direction of the double-headed arrow F, and subjected to balanced compressive stresses σ' and σ'' which are perpendicular both to each other and to the filament direction. Under such conditions, the filaments are stressed in tension as indicated by the arrows T.

In a hollow spherical vessel subjected to external hydrostatic pressure over its entire surface, the external pressure is opposed by balanced circumferential stresses in the wall of the vessel, and any given element of such a body can thus be considered as being subjected to two perpendicular compressive stresses, both essentially parallel to the surface. The general equation for the circumferential stress in a spherical shell under external hydrostatic pressure is

(1)
$$\sigma = \frac{Pr}{2t}$$

where P is the unit pressure, r is the mean radius of the sphere, and t is the wall thickness of the shell. If, now, each such element of the shell body is composed of a unidirectional-filament slab in which all the individual fibres are oriented substantially radially of the sphere and thus normal to the plane of application of the compressive stresses, the fibres in each element of the shell body will be stressed in tension. Thus, no buckling of the filaments can occur, which obviates the requirement of a high degree of straightness

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in the fibres and effective lateral support by the resin. It will be readily recognized that this is precisely opposite to the situation existing in conventional filament-wound spheres, where transverse buckling of the filament windings is resisted only by the lateral support provided by the resin.

It can be shown that the critical pressure P_c for the buckling of a spherical shell of wall thickness $\underline{t}$ and radius $\underline{r}$ is

(2)
$$P_c = k \frac{E}{\sqrt{(1-\gamma^2)}} \left(\frac{t}{r}\right)^2$$

where E is the modulus of elasticity, γ is Poisson's ratio, and $\underline{k}$ is an empirically determinable numerical constant. Deep submergence vessels are also generally characterized by a figure of merit M which is defined by the relation

(3)
$$M = \frac{W}{D}$$

where W is the weight of the vessel, and D is the weight of the water displaced thereby. For a given value of the critical pressure for buckling, the quantity W/D, which is the weight-to-displacement ratio, is related to the nature of the material of which the vessel is made by the proportionality.

(4)
$$\frac{W}{D} \sim \frac{\rho}{\sqrt{E}}$$

where ρ is the density of the wall material. It will be evident that a low value for the ratio W/D represents a large payload capability for the vessel, and from equation (1) that the wall thickness $\underline{t}$ should be in direct proportion to the radius of the vessel, so that vessels of different sizes will have the same pressure capabilities.

From equations (2) to (4) it can be seen, therefore, that for a sphere of a given size and intended for a specified critical pressure, better performance (lower W/D) results from a higher modulus E, which permits a decreased wall thickness $\underline{t}$, and from a lower density ρ. Effective implementation of the principles

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of the present invention thus entails the use of unidirectional fibre and resin building elements having an optimally low value of $1/E$, a ratio which decreases as E increases, E in this case being the transverse modulus of elasticity of the element (i.e. the modulus perpendicular to the filament direction). It is preferred to employ both resin and fibre components of high modulus, since both contribute to the transverse modulus of the composite element. Nevertheless, it will be understood that other factors, e.g. permissible density, weight, etc., may place limitations on the choice of resin and/or fibre for the elements.

Merely by way of example, we have found that excellent results are achieved by using glass filaments (having a modulus of elasticity in the range of about 10,000,000 to 12,500,000 psi) as the fibre component in a resin matrix composed of an epoxy resin system marketed by Minnesota Mining and Manufacturing Company under the designation "1009" (having a modulus of about 430,000 psi). Alternatively, the fibre component of the building elements may include asbestos fibres (modulus in the range of about 24,000,000 to 25,000,000 psi), boron filaments (modulus in the range of about 50,000,000 to 60,000,000 psi), carbon filaments (modulus in the range of about 20,000,000 to 70,000,000 psi), sapphire whiskers, tungsten whiskers, etc. The resin component may be an epoxy resin such as any of those marketed by Union Carbide Corporation under the designations "ERL-2256" (modulus about 550,000 psi), "ERRA-0300" (modulus about 720,000 psi) and "EP-2114" (modulus about 1,030,000 psi), as well as other such resins, and various other synthetic resins such as phenolic resin, melamine resin and the maleic alkyd/styrene copolymer types of polyester resins, characterized by relatively low values of $1/E$. We have found, for example, that an element such as shown in Fig. 7 and composed of an epoxy resin matrix (Minnesota Mining and Manufacturing Company's type "1009")

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having embedded therein unidirectional filaments of "S" glass
(77% of the total volume) can withstand balanced compressive
stresses of 165,000 psi in each of the σ' and σ''
directions.

Figs. 1 and 2 show a hollow sphere 25 constructed of two
hemispheres 25a and 25b each built up in accordance with the
present invention. The method here employed, which we term the
"lune" method, uses as the starting material a procured unidir-
ectional sheet composed of a resin matrix, e.g. epoxy resin,
and glass or other filaments embedded therein, the filaments
extending parallel to each other and to the wide faces of the
sheet. The sheet is first severed into a plurality of thin
strips 26 (Fig.3), the direction of cutting being perpendicular
to both the direction of the filaments and the plane of the
sheet. Each strip 26 thus has a multitude of short, closely
packed filament lengths extending perpendicularly to its
wider faces, as indicated diagrammatically at 26a. The
thickness of the strips 26 will, of course, depend on the intended
structural and strength characteristics of the sphere to be
constructed.

Each strip 26 is then cut into a section 27 having the
shape of a half-lune (Fig. 4), and an adhesive tape 28 having
a pressure-sensitive adhesive on each face thereof is applied
to one face of each half-lunate section 27. As the final prep-
aratory step, each half-lunate section 27 is cut into elements
27a in a rectangular grid pattern (Fig. 5), severing it to,
but not through, the adhesive tape backing. The elements 27a
thus remain adhered to the backing tape, and the assembly thereby
has a two-dimensional formability, i.e. the ability to bend
both longitudinally and transversely.

The manner in which the various half-lunate sections 27
are built up into the form of a hemisphere 25a (or 25b) is

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best shown in Figs. 6 and 6a. The only equipment required for this operation is a destructible spherical mandrel 29 of the appropriate outer diameter, made conveniently of a low-melting alloy, e.g. Wood's metal. As is clearly apparent, the building method involves laying the individual half-lunate sections onto the mandrel with their respective adhesive tape backings in contact with the mandrel. Thus, each half-lunate section is applied to the mandrel by initially positioning the wide end 27b parallel to the "equator" of the mandrel, as indicated in solid lines in Fig. 6a, and then bending the strip over into its final, curved, mandrel-conforming position, as indicated in broken lines in Fig. 6a, so that the apex 27c of the half-lunate section essentially reaches the "pole" of the mandrel. It should be understood that in actual practice it will be preferable to use half-lunate sections 27 of such sizes that when they are adhered to the mandrel, their wider ends 27b are located slightly below the mandrel "equator", for a reason which will become clear as the description proceeds.

After this building operation has been completed, the assembly is vacuum-impregnated on the mandrel with an appropriate thermosetting resin, e.g. epoxy resin, to fill the respective spaces between adjoining half-lunate sections and between adjoining elements 27a, and is cured on the mandrel to complete the setting of the filling resin. Thereafter, the mandrel is removed, as by melting it out, and the interior of the hemisphere is cleaned, at which time the tape 28 is also removed. The annular equatorial surface of the hemisphere is then cut and ground true, so it can mate with another like hemisphere. Two identical hemispheres are finally equatorially joined together by means of an epoxy resin adhesive, for example that marketed by Shell Oil Company under the designation EPON-934. The so-assembled sphere is then again subjected to a curing operation to set the adhesive.

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For a radial-filament sphere of this type, having a 3-inch inner diameter, we have found a wall thickness of 0.180 inch (the component strips being transversely cut to that thickness from a ⅜ inch thick unidirectional sheet of epoxy-bonded glass filaments obtained from the Minnesota Mining and Manufacturing Company and available in various thicknesses) to be sufficient to provide a collapse pressure in excess of 13,000 psi at a weight-to-displacement ratio of 0.53. A comparable filament-wound and internal ring-stiffened construction having a collapse pressure of 13,600 psi is found to have a weight-to-displacement ratio of 0.62, the increase of about 17% in weight representing a correspondingly reduced payload capability.

A somewhat different method, herein termed the "1/3 octant" method, of building a radial-filament sphere from unidirectional resin and filament sheets is illustrated in Figs. 8 to 10. As before, a sphere 30 (Fig. 8) may be constructed by joining two identical hemispheres 30a and 30b. Each hemisphere is, however, made up of four quadrant sectors 31, each of which is an octant of a sphere, and each quadrant of the hemisphere is made up of three substantially identical, four-sided, spherically curved sections 32 (see also Figs. 9 and 10) each having a one-third octant shape the area and contours of which can be easily calculated from known geometrical considerations.

As the first step of the preferred hemisphere-building method according to this aspect of the present invention, a number of elongated planar strips 33 (Fig. 9a) somewhat greater than the number required for the one-third octant section 32 to be formed are assembled in side-by-side relation and clamped together against a flat surface, with the fibres oriented normal to said surface. A thin sheet 34 of rubber or other flexible material capable of being formed smoothly over a doubly curved surface is then cemented to the entire exposed

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face of this assembly of strips. The assembled strips are
then cut transversely to their lines of juncture, down to but
not through the flexible sheet 34, resulting in the formation
of a relatively large number of small elements 33a which are
cemented only to the rubber sheet but not to each other. This
section is then laid onto a spherically curved mandrel of proper
radius (with the sheet 34 against the mandrel surface) and
is impregnated with epoxy resin to fill the numerous
essentially V-shaped cracks between the elements. After the
resin filling is cured, the section is cleaned of the sheet
backing and excess resin, and cut and trimmed to the exact
contours of a one-third octant as shown in Fig. 9. Three
such cured sections 32 are then assembled on a hemispherical
mandrel and fitted together to constitute an octant 31 of the
sphere, and epoxy resin is applied to the mating or abutting
surfaces of the sections and cured to complete the octant.
Four such octants, properly trimmed, are assembled on a spherical
mandrel, and epoxy resin is applied to their mating surfaces
and cured, to complete the hemisphere (30a or 30b). Two such
hemispheres are thereafter equatorially joined as before by
an epoxy resin bond to complete the sphere.

Yet another preferred method of building a hollow sphere
according to the present invention is illustrated in Figs. 11
to 15. In this method, herein termed the "strip" method, elon-
gated strips 35 of unidirectional elements are employed, each
strip consisting of an end-to-end arrangement of a number of
such elements adhered at one face to a double-faced, pressure
sensitive adhesive tape 37 (similar to the tape 28 shown in
Figs. 2, 4 and 6). The filaments are, as before, perpendicular
to the tape backing. The method involves first forming an
equatorial region, one or more strips in width, along the
"equator" of the spherical mandrel 29 (Fig. 11), the strips 35

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being secured to the mandrel by the tape. Thereafter, one or more strips 35a are laid along a great circle path across the "pole" of the mandrel, joining two diametrally opposite sections of the uppermost edge of the topmost equatorial strip 35 (Figs. 12 and 13). Two quarter-circle strips 35b are then laid onto the mandrel, spaced 90° from strips 35a and extending from opposite sides of polar strips 35a down to the corresponding diametrally opposed sections of the upper edge of the topmost equatorial band 35 (Fig.14). At this stage, therefore, there are still open four spherically triangular sections of the hemisphere. These are then filled in progressively by applying further strips 35c etc. (Fig.15) cut to suitable shape where they meet corners of the respective triangles. It is again noted that in actual practice the lowermost strip 35 will preferably extend somewhat below the "equator" of the mandrel 29. After the hemisphere has been completed in this manner, the cracks are filled in with epoxy resin as previously described, and the entire assembly is cured and, after removal of the mandrel and the tape, machined accurately in the equatorial plane. A complete sphere is then formed, as above, by cementing two such hemispheres to each other along their equatorial edges.

Despite differences in the various above-described methods of construction, all spheres built up in accordance with the principles of the present invention will perform substantially equally well under identical environmental conditions, subject to the qualification that the presence of the resin-filled V-joints or spaces between adjoining elements in the spheres produced by the "lune", "1/3-octant" and "strip" methods of construction reduces slightly the critical pressure of the shell. It will be apparent, however, that such V-spaces may be filled with tapered pieces of unidirectional fibre-

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reinforced resin cut from the same material as the other
elements, which pieces would be cemented in place with the
fibre lengths therein also oriented substantially radially
of the sphere, whereby the aforesaid slight decrease in
critical pressure could be avoided.   In any event, the
effectiveness of all these spheres in sustaining extremely
high external pressures stems directly from the radial
orientation of the filaments which provides strength and
elastic stability far beyond those of conventional filament-
wound constructions.   Stated in other words, the radial filaments
in the body according to the present invention are circum-
ferentially isotropic, i.e. they are equally effective in all
circumferential directions, whereas in conventional filament-
wound structures a given filament provides support primarily
in a single direction, which makes it approximately one-half
as effective as the filaments in the structures according to
the present invention.

It should also be noted that the uncured unidirectional
filament and resin material, which is used to make the basic
building elements of the spheres, generally may be relatively
resin-rich (resin about 35 to 50% of the total volume) and
thus has a maximum filament content of about 65%. We have
found it advantageous, however, to use a filament content above
about 65% and preferably in the range of about 75 to 90% of
the total volume. This condition can be readily achieved by
squeezing out some of the resin from the uncured material
prior to the curing thereof. The reason is that with a higher
filament content in the shell wall, the sphere can withstand
higher external hydrostatic pressures. Nevertheless, the
principles of the present invention can also be implemented by
using the original material of unreduced resin content, it
being understood that the critical pressure rating of a sphere

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so produced will be somewhat lower than that of a sphere having a reduced resin content and thus an increased fibre content.

As an example of the present invention, we have constructed a radial-filament sphere 3 inches in diameter, by the method of Figs. 11 to 15 described herein, from epoxy resin sheet reinforced with fibreglass filaments, the resin having a modulus of elasticity of 430,000 psi and the glass of modulus 12,400,00 psi (supplied by Minnesota Mining and Manufacturing Company under the designation 1009-29A). The volume fraction of filaments present in the sphere was 77% and the sphere had a weight-to-displacement ratio (W/D) of 0.50. In actual tests, this sphere sustained an external hydrostatic pressure of 25,000 psi without failure.

Still further advantages of the body according to the present invention will become evident from a consideration and comparison of Figs. 16 and 16a of the drawings. Thus, as shown in Fig. 16, in a radial-filament spherical shell 49 it is possible to provide a port opening 50 with radial boundary surfaces, as indicated by the broken lines 50a and 50b. Since the filaments are substantially radially oriented, the port opening can be formed by cutting a segment of suitable size directly out of the shell wall without introducing any end-loading stresses, and without any need to provide means for preventing failure of the structure by spreading or delamination of the wall. By way of contradistinction, as shown in Fig.16a in a conventional filament-wound spherical shell 51 the provision of a port opening 52, even with radial boundary surfaces, entails cutting across the filaments, which automatically introduces end-loading stresses and makes it imperative to provide supporting flanges at the opening to prevent failure by spreading or delamination. From this it will be appreciated that in the event a portion of a radial-filament sphere is damaged, it is possible to repair the same quite easily, since

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it is necessary simply to cut out the damaged portion with an
identical mating radial-filament section which can be cemented
in place to repair the shell without loss of strength. It will
be equally evident that this type of repair is impossible in
a conventional filament-wound shell since the severed filaments
around the damaged area cannot be reconnected.

Yet another advantage of the body of the present invention
is that a sphere of this type need not be provided with polar
end fittings or caps to provide access to the interior of
the sphere. Especially where the sphere is initially constructed
of two identical hemispheres, it is possible to insert the
payload, e.g. the instruments and/or other materials, into
one of the hemispheres prior to the cementing thereof to the
other hemisphere for completion of the sphere, whereby the
entire interior of the sphere is available for payload. This
is essentially impossible in a filament-wound sphere which at
all times requires the provision of generally metal polar caps
or fittings to provide access to the interior of the sphere,
and since a filament-wound sphere can only be formed as an
entity, the polar openings therein must of necessity be relatively
small, limiting the degree of access obtainable and concomitantly
limiting the sizes and character of instruments which can be
inserted into the sphere to width dimensions less than the
diameter of such openings. In addition, the need for metal
polar fittings in a filament-wound sphere increases its weight-
to-displacement ratio which, as previously mentioned, decreases
its payload capability in corresponding degree.

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The claims defining the invention are as follows:-

1.   A method of constructing a hollow, spherical body comprising the steps of preparing a number of sheets of thermosetting resin, reinforced with filaments having a desired or selected modulus of elasticity, the filaments extending from one major planar surface of the sheet to an opposite major planar surface of the sheet substantially normal to the surfaces thereof, the method comprising cutting elements from one or more sheets and assembling the elements into the form of a spherical body with the filaments aligned substantially radially of the body, characterized in that the number of elements are adhered to a backing sheet with the filaments normal to the plane of the backing sheet, the desired number of backing sheets with elements thereon are applied to a mandrel having a spherical or part-spherical surface to form a spherical structure thereon, the backing sheet being on the side adjacent to the mandrel, any spaces between adjacent elements are filled with uncured resin, and the structure is then subjected to a curing treatment for any uncured resin.

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2 A method according to claim 1 in which the backing sheet is applied to the sheet material before this is cut into elements.

3 A method according to claim 1 or claim 2 in which the elements are formed by cutting the sheet material in a rectangular grid pattern.

4 A method according to any one of the preceding claims in which the sheet material is cured before it is cut to form the elements.

5 A method according to any one of the preceding claims in which the backing sheet is a double-faced pressure-sensitive adhesive tape.

6 A method according to any one of claims 1 to 4 in which the backing sheet is a sheet of flexible material

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and is secured to ~~the face of~~ the sheet material or elements cut therefrom by cementing.   ---

7 A method according to any one of the preceding claims in which a hemispherical body is assembled on a spherical mandrel, and is subsequently bonded by resin to a similar hemispherical body, the resin then being cured to result in an integral sphere.

8 A method according to any one of the preceding claims in which the sheet material is cut to form half-lunate sections, backing sheets are applied to one surface of the sections, the sections are cut into elements in a rectangular grid pattern and the backing sheets bearing the cut sections are applied to a spherical mandrel, the wider ends of the sections lying on the equatorial line of the mandrel and the points of the sections meeting at the pole of the mandrel, to form a hemisphere.

9 A method according to any one of claims 1 to 7 in which sheet material is applied to a backing sheet and is also cut into elements in a rectilinear grid pattern, ~~this assembly is~~ cut to form a section of roughly one-third octant shape, the section is placed on a spherical mandrel with the backing sheet contacting the mandrel, the spaces between the elements are filled with resin which is then cured, and the section is then trimmed to an exact one-third octant; subsequently three such one-third octant sections are secured together by resin on a further mandrel to form octants, the resin then being cured, and four of the resultant octants are assembled into a hemisphere, the wide end of each octant lying on the equatorial line of a mandrel, and the narrow ends thereof meeting at the pole.

10 A method according to any one of claims 1 to 7 in which strip-form sections of sheet material have a backing sheet applied thereto and are then cut across their width

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to form a series of elements adhering to the backing
sheet, and a hemisphere is built up on a spherical
mandrel by first applying at least one strip to the
mandrel as an equatorial band, then at least one strip
over the pole of the mandrel from one edge to the
diametrically opposite edge of the equatorial band,
then at least one strip on each side of the polar band
extending transversely thereto to the edge of the equa-
torial band, and finally angularly directed strips within
each of the spherical triangles previously defined on
the mandrel surface until the triangles are completely
filled.

11.   A hollow spherically curved shell-type body
constructed by a method according to any one of the
preceding claims.

                    DATED THIS 17TH DAY OF DECEMBER, 1968
                            UNIROYAL, INC.

                                Agent for the Applicants.
   EDWD. WATERS & SONS,
   30 RUSSELL STREET,
   MELBOURNE. VIC. 3000.
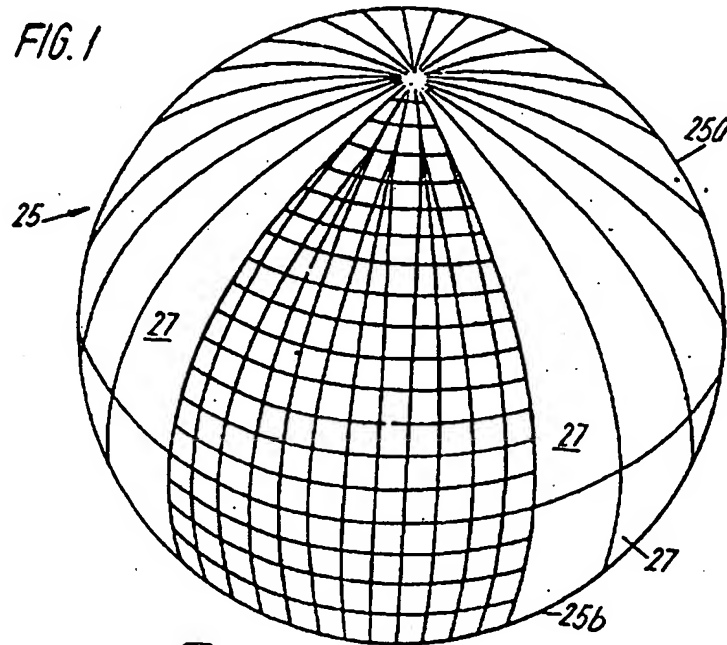
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FIG.1

250

25

27

27

27

25b

FIG.3

26

26a

25

27 27 27

FIG.2

FIG.4

28

27

27a 27 27c

27b

FIG.5

2 1

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17.276 167

FIG.6

29

28

27C

27

29

27

FIG.7

28

27

27

σ'

σ''

27

29

F

σ''

B

σ'

T

T

276

FIG.6Q

33

FIG.9Q

330

32

330

10

10

FIG.9

300

31

32

31

30

32

31

330

32

330

32

30b

31

FIG.10

34

FIG.8

23
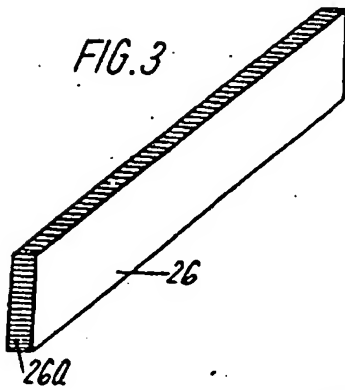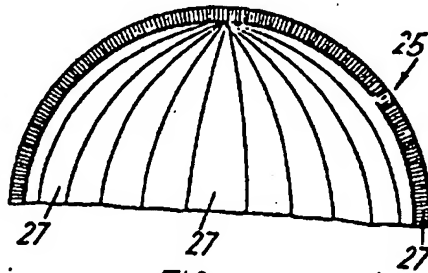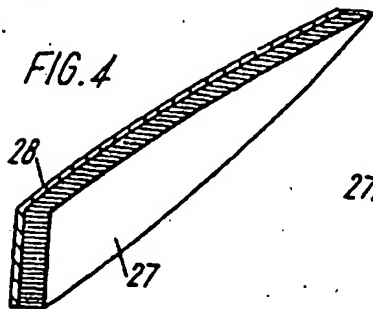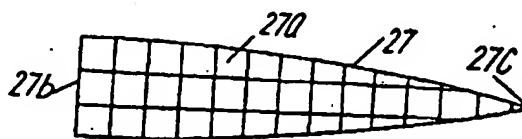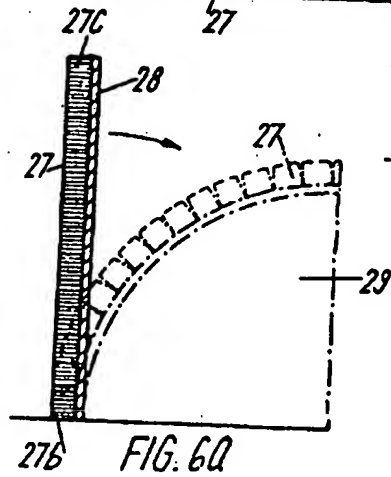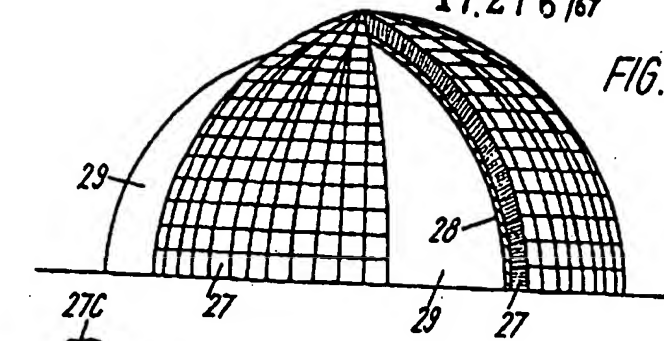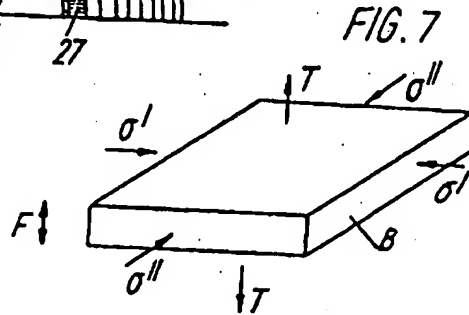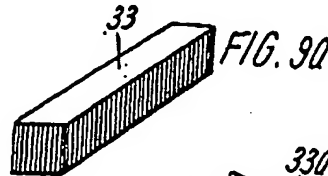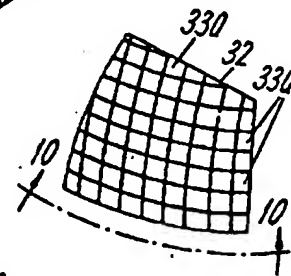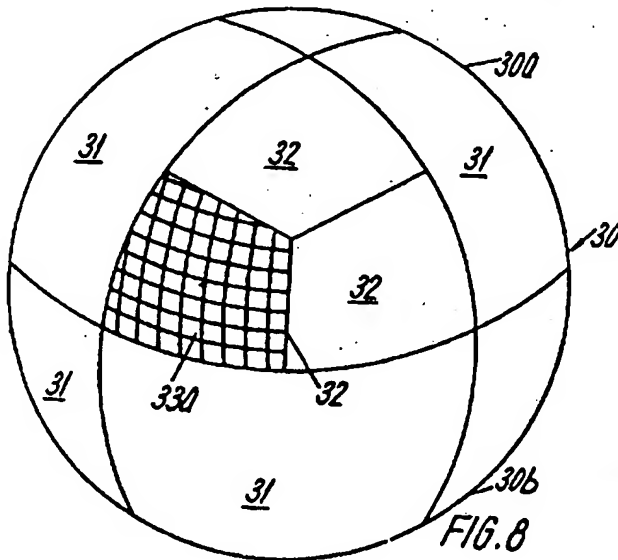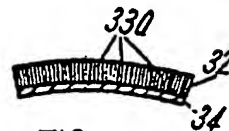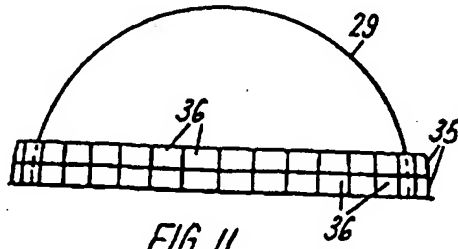
424.478

FIG. 11
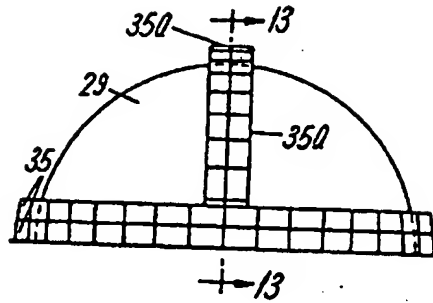
FIG. 12
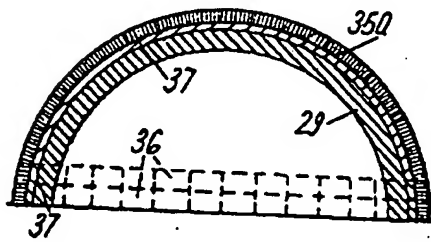
FIG. 13

FIG. 14

FIG. 15

2.5

4 2 4. 4 7 8

FIG. 16a

FIG 16